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REPORT ON

LITTLE TUNNEL
STABILITY ASSESSMENT
CUMBERLAND GAP, TENNESSEE

Submitted to:

Vaughn & Melton Engineers
P.O. Box 1425
Middlesboro, Kentucky 40965

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April 1995

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April 12, 1995 953-3720

Vaughn & Melton Engineers
P.O. Box 1425
Middlesboro, Kentucky 40965

Attn: Mr. Lewis N. Melton

RE: REPORT ON LITTLE TUNNEL
STABILITY ASSESSMENT
CUMBERLAND GAP, TENNESSEE

Gentlemen:

We are pleased to submit this report on the recent rock fall and condition survey in Little Tunnel, Tennessee. The report discusses the design and comparative costs of several options for stabilizing the tunnel and the possibility of using the tunnel as a trail or bike path.

The selection of the method for stabilizing the tunnel should be made by the National Park Service as it will depend on the funds available, the need to construct a trail and the maintenance costs. These issues and the risks associated with each option for stabilizing the tunnel are discussed in the report. Please note that the cost estimates in this report are preliminary and should be reviewed by the FHWA who have more up-to-date, actual construction costs at Cumberland Gap.

If you or the FHWA or the NPS have any questions or comments on the report, please do not hesitate to contact us. I would like to express my thanks to the FHWA personnel at the Cumberland Gap Project Office and to David Robinson for useful discussion and input.

Very truly yours,

GOLDER ASSOCIATES INC.

Richard W. Humphries, P.E.
Senior Consultant and Principal

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Program Director and Principal

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TABLE OF CONTENTS

1.0 INTRODUCTION

Little Tunnel is a 100 year old, disused railroad tunnel which crosses under the US25E/US 58 interchange between the towns of Cumberland Gap and Harrogate, Tennessee in the Cumberland Gap National Historic Park. The tunnel is currently used as a utility corridor for telephone cables, TV cable, power cable, water and sewer lines. The National Park Service is interested in evaluating whether the tunnel can be used as a trail and bike path connecting different areas of the park.

The tunnel is approximately 1,000 feet long. It is partially brick lined and partially lined with timber arches, or sets, and wooden lagging. In 1986, two timber sets collapsed causing a rock fall in the tunnel. Repairs and additional stabilization were done in 1987 and 1990.

One additional set collapsed in the timber lined section in 1994. To examine the cause of this collapse, Federal Highway Administration (FHWA) requested Vaughn & Melton and Golder Associates to review the stability of the tunnel. On January 25 and 26, 1995, Richard Humphries, of Golder Associates, and Don Slaven, of Vaughn & Melton, logged the condition of the timber sets, the repaired sections, and the brick lining, and discussed the technical aspects of the project with the members of FHWA at the Cumberland Gap Project Office.

The object of this report is to describe these stability conditions and to present options for stabilizing the tunnel so that it could be used as a trail and bike path. Design of the stabilization can proceed once the preferred option for stabilization is selected by National Park Service and FHWA.

2.0 EXISTING CONDITIONS IN LITTLE TUNNEL

The original excavated length of Little Tunnel was 1,034 feet. Two hundred and seventy feet from the west portal was brick lined and the remaining 758 feet was lined with 12 inch by 12 inch timber sets at four feet on centers with lagging between the timber sets. As part of the construction of US25E/US 58 interchange, approximately 200 feet has been added to the west end of the tunnel in the form of a covered, corrugated steel arch.

In 1986, Golder Associates logged the stability conditions in the tunnel and prepared designs for the repairs to the most critical sections of the tunnel. The report on the stability evaluation of the tunnel is presented in a report dated May 1986, which is attached to this report as Appendix A. The design drawings for the repairs to Little Tunnel and the as-built mark-ups are available in the FHWA office at the Cumberland Gap Tunnel Project. The tunnel log from the 1986 stability evaluation is given on Figure 3 of Appendix A. During the visit to Little Tunnel on January 25 and 26, 1995, the tunnel was relogged on the original logging sheet. This relogging is shown on Figure 2 of this report.

A description of the geology of the tunnel is given in Appendix A. The west end of the tunnel, above the brick lining, is a horizontally bedded shale unit of the Rockwood formation, while the eastern end of the tunnel, above the timber lined portion of the tunnel, is a sub-horizontally bedded limestone unit with occasional calcareous shale interbeds of the Sequatchie formation.

The brick lining in the tunnel is in excellent condition and there is no observable deterioration since the 1986 logging. However, the timber sets and wooden lagging in the remainder of the tunnel vary significantly from severely deteriorated to apparently solid and stable. In general, in this timber lined section of the tunnel, pieces of rock have broken loose from the original excavated tunnel section and are lying on the timber sets and lagging, as shown on Figure 1. The horizontal limestone beds have stoped up and appear to have formed a stable rock crown above the timber sets, with a void between the loose rock and the rock crown. The load of loose rock that is sitting on top of the timbers varies considerably. In places, it is severely overstressing the timber sets.

During the repairs to the tunnel in 1987, timber sets were removed at three locations. At each of these locations, the rock crown that remained after removal of the sets was stable, though the crown had stoped up to a maximum of about 12 feet above the top of the timber sets. The locations of the three repaired areas are shown on the log of the conditions in the tunnel on Figure 2. A similar stable crown can be seen above the zone that collapsed in the 1994 rock falls.

In general, there has been significant deterioration in the condition of the timbers in the tunnel over the nine years since the previous logging. Many of the timbers have rotted significantly and some of the timber sets are distorted from the load of the loose rock resting on top of them.

The log of conditions of the timber sets that is shown on Figure 2 is self explanatory. However, the following areas are of particular concern:

- ❑ Bays 164 through 176. In this zone, between two previously repaired zones, there has been significant deterioration of the timber and many of the sets are distorted from the load of the loose rock on top of the lagging. According to Don Slaven, who inspected the repairs in the two adjacent sections in 1987, there is approximately ten feet of loose rock resting on top of the wooden lagging and there is a void big enough for a man to pass through below the rock crown of the tunnel. This zone appears as though it could fail at any time.
- ❑ Bays 151 through 159. This zone of the tunnel is relatively wet and many of the timbers have deteriorated significantly since 1986. The area does not appear to be overstressed but the condition of the timbers indicates that failure could happen soon.
- ❑ Bays 132 through 138. Several of the legs and haunch members on the north side of the tunnel are severely deteriorated.
- ❑ Bays 112 through 115, Bays 83 through 88, Bays 72 through 77, Bays 52 through 54, Bays 44 through 47, Bays 18 through 22. All these zones have rotten timbers which have deteriorated significantly since the 1986 logging.

In addition to the zones described above, there are a number of smaller zones or particular members of a timber set that are rotten to varying degrees. The locations of these are shown on Figure 2.

3.0 1994 ROCK FALL

The crown and haunch members of set 68/69 failed in 1994, causing a rock fall onto the floor of the tunnel. The volume of rock that fell onto the tunnel floor is relatively small and is estimated at approximately five cubic yards. The failure appears to have occurred because the timber set decayed and the haunch members fell off the leg members of the set, and not because of a high loading on the set from loose rock above it. In this area of the tunnel, the rock crown has stoped up only about three feet and the adjacent timber sets are not heavily loaded. The rock in the crown of the tunnel appears to have formed a stable arch and is not in need of immediate repair.

While the rock fall at set 68/69 is not particularly big and has not caused any significant damage, the issue of concern is that this set was not logged as being deteriorated or distorted in the 1986 logging. In particular, there was no record suggesting that this and its neighboring timber sets were in any worse condition than other sets in the tunnel. From this, one can infer that other sets in the tunnel could deteriorate and collapse. We do not know of any low-cost technique for estimating and monitoring the deterioration of timbers. Lacking such assessment, it is not safe to assume that any zone of the tunnel is stable and safe.

4.0 REPAIRS AND STABILIZATION IN 1987 AND 1990

Six zones in the timber lined section of the tunnel were stabilized or strengthened in 1987 and 1990. Details of these repairs are given in the As-Built Drawings which are in the FHWA office at Cumberland Gap. Two different types of stabilization and strengthening were used. These are:

- Bays 177 through 189, Bays 160 through 163 and Bays 105 and 106. Soon after the initial logging of the tunnel in February 1986, the zone from Bays 184 through 187 collapsed and deposited a large pile of loose rock and timber on the floor of the tunnel. During the repairs of this collapsed zone, the adjacent timber sets, between the west end of the brick lining (next to Bay 189) through to Bay 177, were removed along with the loose rock that the sets were supporting. At the same time the sets between Bays 160 and 163 and between Bays 105 and 106 were removed. The rock crown above these removed zones was scaled and rockbolted with ten foot long rockbolts at approximately four feet on centers. This work was done in 1987. Over the next three years there was some loosening and slaking of the rock around the newly installed rockbolts so, as part of the main Cumberland Gap Tunnel Construction Contract, two to three inches of shotcrete was placed on the crown of the tunnel in these three zones. At present, all three zones appear to be in good condition. There is no indication of cracking or distress in the shotcrete though there are a few minor drips around Bays 180 to 182, which is of no structural concern.
- Bays 42 and 43, Bays 23 and 24, and Bays 1 through 12. There is limited cover at the east portal of the tunnel. In 1986, there was a surface sinkhole above Bays 8 through 11 and it was considered unlikely that there was sufficient rock cover to form a stable arch for rockbolting and shotcreting. Consequently, the zone from Bays 1 through 12 was strengthened by constructing a reinforced concrete structure between each of the existing timber sets and leaving the timber sets in place. The same type of strengthening was used for Bays 23 and 24 and Bays 42 and 43. This type of strengthening appears to have worked well. Apparently, it was felt at the time that this type of strengthening is more expensive and time consuming than removing the timber sets and rockbolting and shotcreting the rock crown of the tunnel.

At the same time that this strengthening work was done in 1987, additional lagging was installed in many of the bays where the previous lagging was deteriorated or missing. In addition, set 166/167 was strengthened in the crown. During the logging of the tunnel in January 1995, the state of the lagging was not recorded because it is considered that the main cause for concern for the stability of the tunnel is dependent on the condition of the timber sets rather than the lagging.

5.0 OPTIONS FOR STABILIZING THE TUNNEL

There are seven possible options that can be considered for stabilizing and strengthening Little Tunnel. Each of these options has a different capital cost, maintenance costs, and risks to the public and maintenance workers who may be in the tunnel. In addition, some of these options could allow the tunnel to be used as a trail or bike path.

Preliminary comparative cost estimates for stabilizing and strengthening the tunnel and for annual maintenance have been prepared for each option. The brick lined section, the corrugated metal cut-and-cover section, and the sections at the east and west ends of the timber line section that were previously stabilized are considered to be stable and not in need of further work.

The options that could be considered for Little Tunnel are as follows:

5.1 Option 1 - Do Nothing Option

As mentioned previously, the rock fall that occurred in 1994 has not left the tunnel in a critically unstable condition. Progressive collapse is not expected in this zone and the volume of material from the rock fall is relatively small. Consequently, there is no pressing need to clean up or stabilize this section of the tunnel. Indeed, if it is not essential to use the tunnel as a utility corridor or for a future trail, it would be feasible to do nothing in the tunnel. There has been significant deterioration in the condition of the timber sets since 1986, and it is likely that there will be successive rock falls in the tunnel as the timber sets deteriorate further. However, even if there were to be a number of collapses of various areas of timber sets, it is likely that the crown of the tunnel has formed a stable arch in its present configuration and this arch will probably not collapse progressively and stope to the surface within the lifetime of the Cumberland Gap project.

If it is decided to select this "do nothing" option, it would be advisable to remove the telephone and TV cables that are attached to the walls of the tunnel, as they may be damaged during future rock falls. These cables could be installed in conduits which could be buried in the crushed stone invert of the tunnel. The utility companies should not then be allowed access to the buried conduits in the tunnel once they are installed. The same applies to the electric, sewer and water pipes in the invert of the tunnel. If this option is selected, it will be essential to keep all personnel out of the tunnel except those who are experienced in tunneling and understand the stability concerns of going into the tunnel.

The cost of this option is approximately $10,000 for reinstallation of the TV and telephone cables. There should be no maintenance.

5.2 Option 2 - Repair Collapsed Zone and Stabilize Worst Areas

As mentioned previously, there are a number of zones in the tunnel where the timber sets are severely deteriorated and/or overstressed. These zones are in imminent danger of collapse and need to be repaired if the tunnel is to continue to be used as a utility corridor with access for utility maintenance. The most economical way of repairing these zones would be to remove the timber sets in these specific areas and stabilize the crown by installing rockbolts and shotcrete in a similar way to the previous repairs.

The estimated cost to these repairs is $229,100 and it is estimated that there would be an on-going need for repairs as sets deteriorate and collapse. The estimated maintenance cost are estimated at approximately $30,000 per year. Even if these repairs were to be carried out, there is still a risk that other sets would collapse at any time and, consequently, it is not recommended that the tunnel be used for a trail or a bike path by use by the public. Further, the condition of the tunnel should be examined by an engineer experienced in tunnel stability before utility maintenance personnel enter the tunnel.

5.3 Option 3 - Install Corrugated Metal Pipe

A simple method of providing a safe trail or bike path through the tunnel would be to install a, thick-walled corrugated metal pipe through the timber lined section of the tunnel, as shown on Figure 3. This pipe would be similar to the corrugated metal pipe that was constructed to extend the tunnel at the west portal. These corrugated metal pipes are off-the-shelf items which can be installed very rapidly.

It will be necessary to place backfill above the pipe to provide a cushion in the event of future roof falls. Access to the space above the pipe is very limited so placing the backfill will be difficult.

The estimated cost of this option is $351,600 and there should be no maintenance costs.

5.4 Option 4 - Remove all Timber Sets: Shotcrete and Rockbolt Crown of Tunnel

This option would involve removing all of the remaining timber sets and rockbolting and shotcreting the rock crown of the tunnel. This method of stabilizing the tunnel worked well during the 1987 and 1990 repairs and is shown on Figure 4. The initial cost is estimated to be approximately $403,000 and there would be no maintenance cost. It would be necessary to investigate the rock conditions at the east end of the tunnel to ensure that there is sufficient rock cover to install rockbolts in the crown of the tunnel. With this option, it would be possible for the tunnel to be used as a trail or bike path and to have its continued use as a utility corridor.

5.5 Option 5 - Construct Concrete Structures in Bays Between Timber Sets

This method would involve constructing reinforcing concrete beams and columns between the existing timber sets using the same design as the previous repairs at the east end of the tunnel. This repair work was found to be relatively slow and would be dangerous as it would be necessary to work around the existing timber sets, some of which are likely to collapse at any time. It is estimated to be more expensive than the shotcrete and rockbolt option (Option 4) and would not be quite as stable as the existing sets would be left in place and may rot out completely over time. The tunnel could be used for a trail or bike path if this option were selected, but it would require periodic inspection of the timber sets to ensure that they have not completely rotted through. The estimated cost of this option is $463,000 and there would probably be no maintenance cost.

5.6 Option 6 - Backfill Tunnel

It will be possible to completely backfill the tunnel with soil or rockfill. This would be relatively inexpensive (estimated at $122,000) and would be maintenance free. However, the tunnel could not be used for a trail or bike path and there would then be no access to the utilities through the tunnel. As with Option 1, the TV and telephone cables could be placed in conduits in the invert of the tunnel.

The preliminary comparative cost estimates for each option are presented in Table 1. The capital cost estimates are based on calculated quantities and unit rates from similar work on the Cumberland Gap Project. The maintenance costs are less certain and are based on our judgment of the frequency that rock falls would occur in the tunnel and the need for repairs after each rock fall. Table 2 shows a comparison of the different options with their estimated initial capital costs, estimated maintenance costs, relative risks and the possibility of using the tunnel as a trail. The costs of lighting, paving, signposting, bicycle facilities, etc., have not been included in the cost estimates given for each option.

TABLE 1
COST ESTIMATES

OPTION 1 - DO NOTHING

Initial Capital Cost — Est. $10,000

Installation of telephone and TV cables in conduits in invert of tunnel

Maintenance Costs — not required — $0/year

OPTION 2 - REPAIR COLLAPSED ZONE AND STABILIZE WORST AREAS

Initial Capital Cost

- Length to be stabilized:

Bays 18 - 22	=	5'x4'	=	20'
Bays 30 - 33	=	4'x4'	=	16'
Bays 52 - 54	=	3'x4'	=	12'
Bays 67 - 93	=	27'x4'	=	108'
Bays 112 - 115	=	4'x4'	=	16'
Bays 132 - 138	=	7'x4'	=	28'
Bays 147 - 159	=	13'x4'	=	52'
Bays 164 - 176	=	13'x4'	=	52'
				304'

- Debris removal and set demolishing
  est. 18' wide x 5' x 304' = 1013 yd^3 at $\$20/yd^3$ = $20,260

- Rockbolts
  10' rockbolts: 5 across crown + 2 in. sidewalls every 4 ft.
  = 7x (304'/4) x 10' = 5,320 lin. ft. at $12/ft = $63,840

- Shotcrete
  3" thick (ave.) over 304' x 25' + 25% rebound
  = 70 yd^3 + 25% say 90 yd^3 at $\$700/yd^3$ = $63,000

- Mobilization
  est. at 15% $22,000

- Engineering and Construction Management
  est. $60,000

Est. Capital Cost $229,100

Maintenance Cost

Est.: 1 roof fall every 5 years at $150,000 for repairs average = $30,000/year

OPTION 3 - INSTALL CORRUGATED PIPE BACKFILL TUNNEL

Initial Capital Cost

- 2/3 circumference of 13.5 ft. diameter, thick-walled, corrugated metal pipe, 700 ft. long	$200,000
- Concrete Footing:	
2 sides 18" x 12", 700 ft. long = 76 yd^3 at $350	$26,600
- Backfill above pipe:	
1,500 yd^3 x $40	$60,000
Reinstall TV and electric cables	$5,000
- Mobilization	
est. at 15%	$40,000
- Engineering and Construction Management	
est.	$20,000
Est. Capital Cost	$351,600

Maintenance

None required $0/year

OPTION 4 - REMOVE ALL TIMBER SETS. SHOTCRETE AND ROCKBOLT CROWN OF TUNNEL.

Initial Capital Cost

- Length to be stabilized = Sta. 17+04 to Sta. 10+46
  minus (15'+7'+7'+7') already stabilized = 622'

- Debris removal and set demolishing		
est. 18' x 5' x 622' = 2073 yd^3 at $20/yd^3 =	$41,500	
- Rockbolts		
10' rockbolts: 5 across crown and 2 in sidewalls at 4' on centers		
= 7 x (622/4) x10 = 10,885 lin. ft. at $12/ft. =	$130,620	
- Shotcrete		
3" thick (ave.) over 622' x 25' +25% rebound		
= 144 yd^3 +25% = 180 yd^3 at $700/yd^3 =	$126,000	
- Mobilization	$45,000	
- Engineering and Construction Management est.	$60,000	
Est. Capital Cost		$403,120
Maintenance Cost None required		$0/year

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OPTION 5 - CONSTRUCT CONCRETE STRUCTURES IN BAYS

Initial Capital Cost

- Length to be strengthened: Same as Option 5 = 622' or 141 bays

- Concrete:	141 bays x 3' wide x 15" thick x 50' circumference = 979 yd^3 say 1,000 yd^3 with footing x $350/$yd^3$ including reinforcing, framework and access =	$350,000	
- Mobilization	est.	$53,000	
- Engineering and Construction Management	est.	$60,000	
	Est. Capital Cost =		$463,000

Maintenance Cost

	None Required	$0/year

OPTION 6 - BACKFILL TUNNEL

Initial Capital Cost

- Length to be backfilled is length of existing timber sets = 700 ft. (approx.)

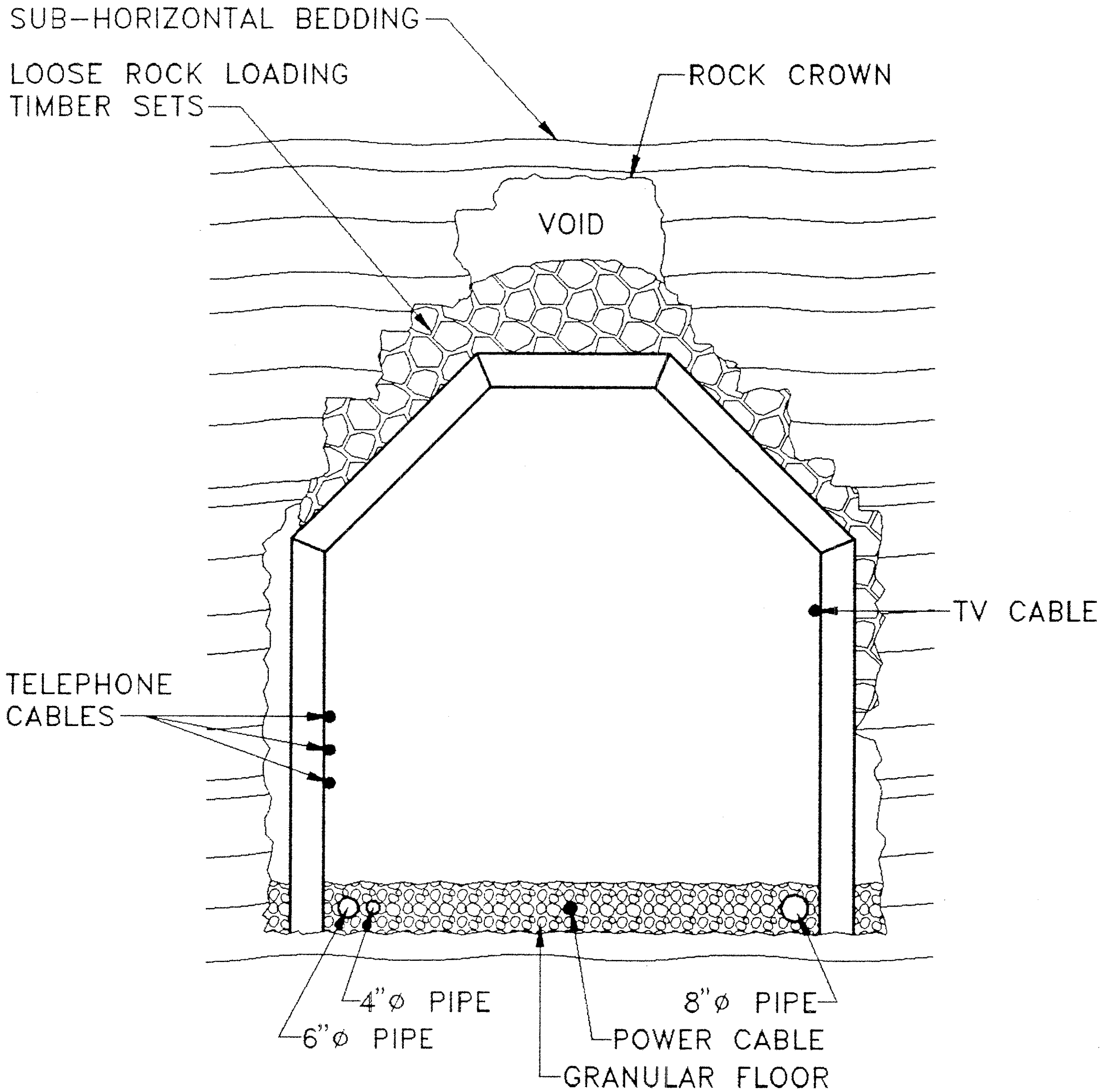
- Volume of backfill to 16' wide x 18' high x 700 ft. = 7,500 yd^3 at $12/$yd^3$ =	$90,000	
- Reinstall telephone and TV cables in conduits	$10,000	
- Mobilization (est.)	$12,000	
- Engineering and Construction Management (est.)	$10,000	
Est. Capital Cost =		$122,000

Maintenance Cost

	None Required	$0/year

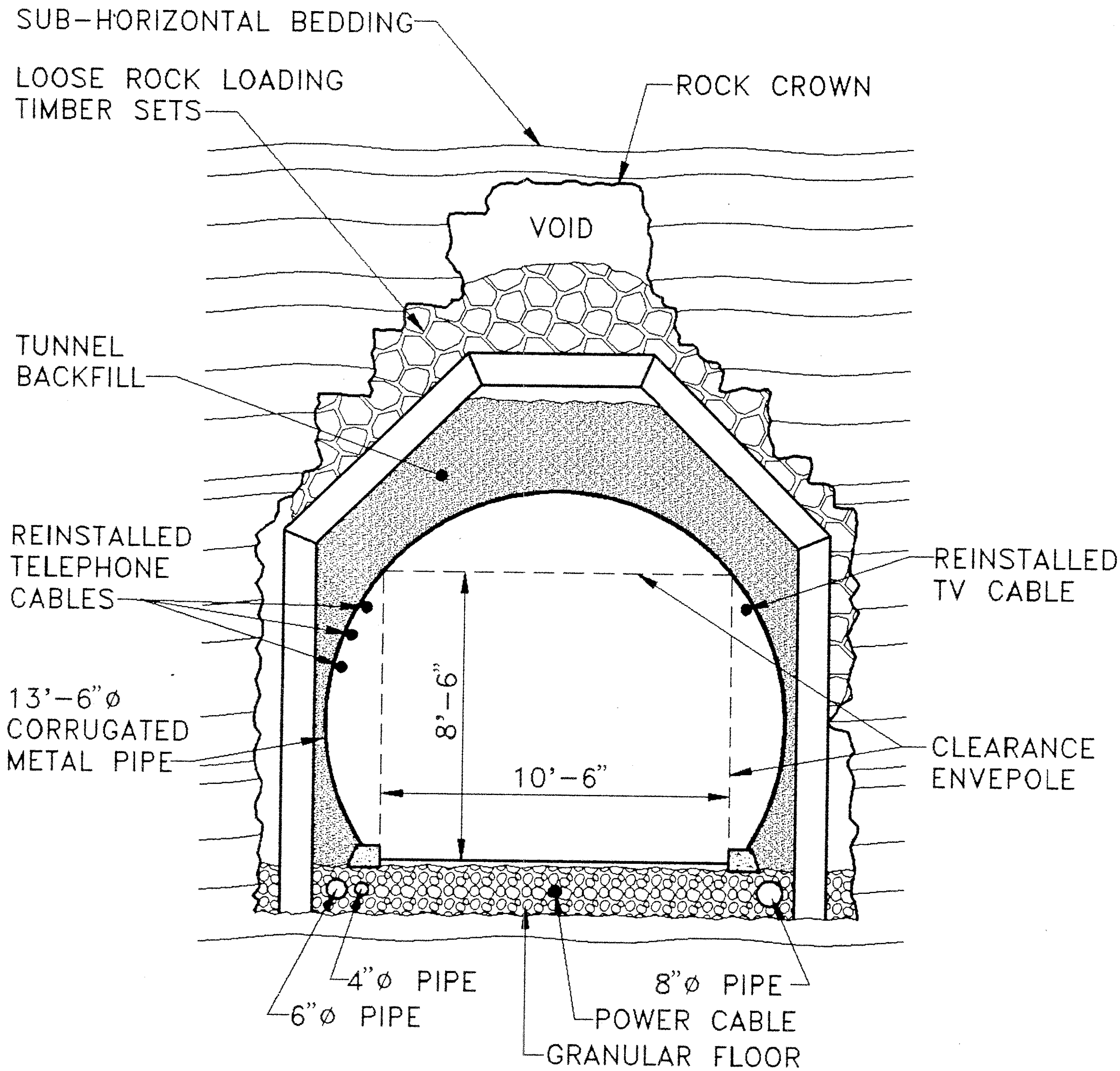
LITTLE TUNNEL - REPAIR OPTIONS

OPTIONS	Comparative Initial Cost ($)	Estimated Maintenance ($/year)	Risk	Use as Trail
1. Do nothing.	$10,000	$0/year	High	No
2. Repair collapse and remove worst timber sets and support with shotcrete and bolts.	$229,100	$30,000/year	Moderate	No
3. Install corrugated pipe and backfill void above pipe.	$351,600	$0/year	Low	Yes
4. Removal all timber sets. Install bolts and shotcrete.	$403,120	$0/year	Low	Yes
5. Construct concrete structures in bays.	$463,000	$0/year	Low to Moderate	Yes
6. Backfill tunnel.	$122,000	$0/year	Low	No



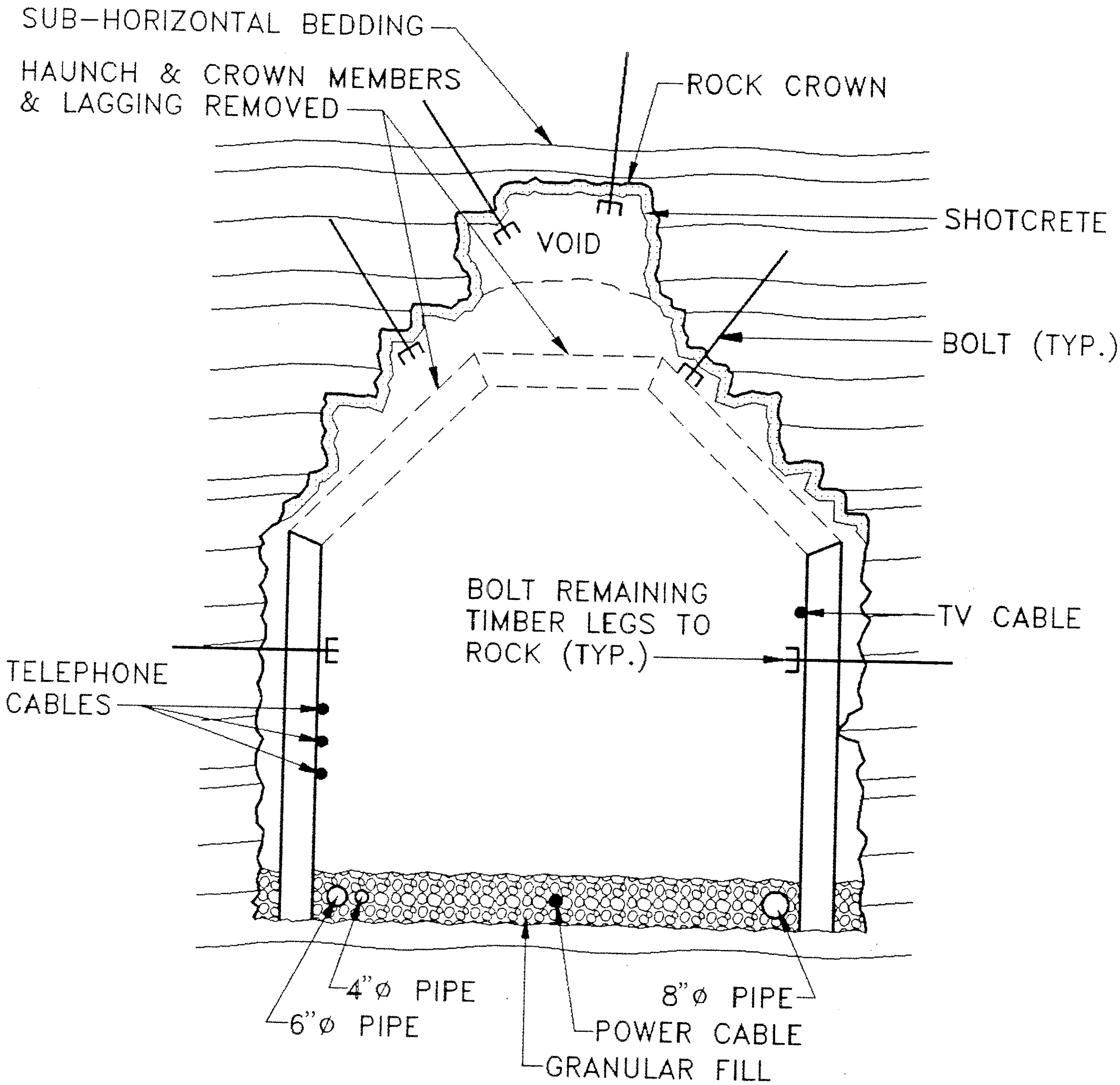
TYPICAL CONDITIONS IN TUNNEL
LINED WITH TIMBER SETS & LAGGING

Golder Associates, Atlanta, Georgia	TITLE: TYPICAL CONDITIONS IN TUNNEL LINED WITH TIMBER SETS & LAGGING						
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720				
	CHECKED	SCALE: NTS	DWG NO. 1	REV. NO.			
	REVIEWED	FILE NO. 953-3720	SUBTITLE	FIGURE NO. 1			



STABILIZATION OPTION 3
INSTALL METAL HALF-PIPE

Golder Associates, Atlanta, Georgia	TITLE: STABILIZATION OPTION 3		
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720
	CHECKED	SCALE: NTS	DWG NO. 3 / REV. NO.
	REVIEWED	FILE NO. 953-3720	SUBTITLE / FIGURE NO. 3



REMOVE TIMBER SETS & STABILIZE ROCK CROWN WITH ROCKBOLTS & SHOTCRETE

Golder Associates, Atlanta, Georgia	TITLE: STABILIZATION OPTION 4				
CLIENT/PROJECT: LITTLE TUNNEL, CUMBERLAND GAP, TN FHWA/NPS	DRAWN: RMS	DATE: 2/95	JOB NO. 953-3720		
	CHECKED	SCALE: NTS	DWG NO. 4	REV. NO.	
	REVIEWED	FILE NO. 953-3720	SUBTITLE	FIGURE NO. 4	